A Living Game of Life

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The Game of Life is a set of cellular automata rules created by John Conway in the 1970s. Since this time it has been studied extensively, and is considered to be the "classic" cellular automata. This paper looks at ways to simulate the Game of Life by using living cells.

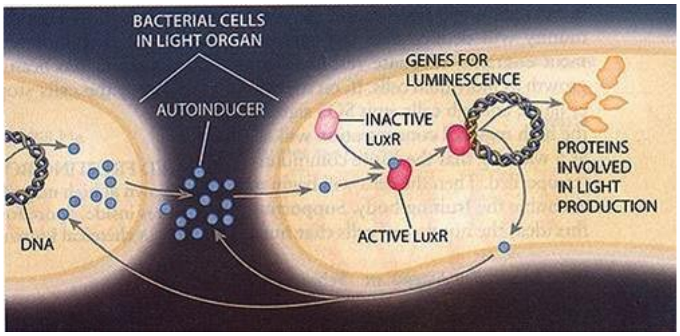
The Game of Life is played on a regular grid of cells. At each update step, if a "live" cell has one or two living neighbors, it stays alive. If a "dead" cell has exactly 3 neighbors, it is born (changes to "live"). Any other condition and the cell dies. These three rules are enough to be computationally universal. That is, the Game of Life can simulate any arbitrary Turing machine. This means that in theory, if we could simulate the Game of Life with living cells, we would have an organic computer.

In order to play the Game of Life, a few key sub-elements have to be present. There must be a regular grid to play on, communication between neighboring cells, implementation of local rules, indication of state, and a way to set initial conditions.

The first step is creating a regular grid of cells. This grid should keep the cells in a fixed position, but allow nutrients and signaling molecules to move around freely. The simplest idea is to use plant cells. Plant cells naturally form grid-like structures with the cell walls. The downside to this method is plant cells are eukaryotes and thus it is more complicated to add DNA information to the cells. The same problem occurs with animal cells. Through tissue engineering, it may be possible to create a regular arrangement of cells. The problem is that it would be harder to add genetic code than in prokaryote cells. The ideal cells to use for the grid would probably be bacteria. By adding plasmids to a bacteria culture, genetic information can easily be transferred to the population. The question that must be solved is then how to create a regular pattern of bacteria cells. Bacteria colonies can be grown on artificial mediums, such as agar. Bacteriostatics, chemicals which stop bacteria growth but do not kill the cells, can be used to freeze the grid once a desired size has been reached, from this point, as long as nutrients are supplied to the cells, the grid should be relatively stable. It may be the case that interesting behaviors will be present on non-regular grids. If this were true, then any bacteria colony would be sufficient, and easy to grow.

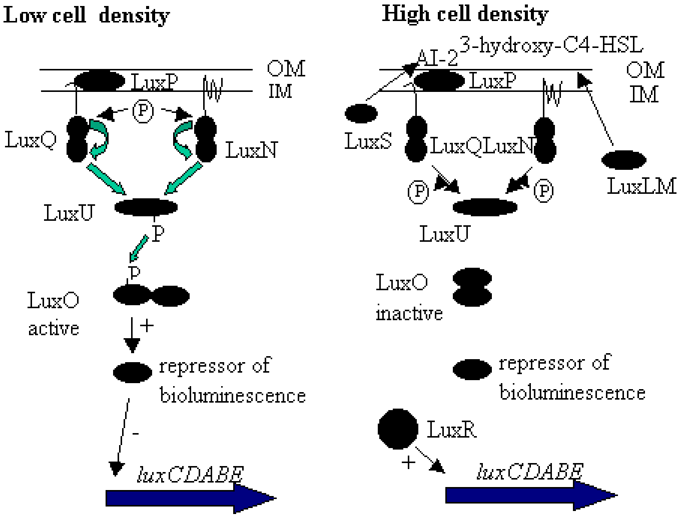
Having a nice grid structure is useless without a way to send signals between the cells. The most straightforward way of doing this would be sending signaling molecules from “living” cells that indicate this state to neighboring cells. Quorum Sensing is a common way to accomplish this in nature. Vibrio harveyi and Vibrio fischeri are both bioluminescent bacteria that glow only once a certain population density has been reached. V. harveyi and V. fisheri use slightly different mechanisms to accomplish this.

V. fischeri



In Vibrio fischeri, low levels of a homoserine lactone (AHL) signaling compound are always being produced. Once a critical population density is reached, the AHL has enough of a concentration to bind to LuxR. This activates LuxR, which promotes the production of more AHL and bioluminescent proteins.

V. harveyi



In Vibrio harveyi, the situation is almost the opposite. At low AHL concentrations, LuxO is phosphorylated and thus activated. It produces a repressor protein which inhibits production of the bioluminescent proteins. At high AHL concentrations, LuxO is dephosphorylated and the repressor is not produced, so the bioluminescent proteins are expressed.

By combining these two systems, and possibly changing which repressor or which promoter is produced, the cell could be turned on at a low concentration but turned back off at a high one. The rules for the Game of Life would have to be expressed by varying the sensitivity of these two thresholds.

The state of a given cell would be indicated by its production of the AHL and bioluminescent proteins. Glowing (and AHL signaling) indicates the cell is “alive” while not glowing and not signaling indicates the cell is “dead”. This method seems much more reasonable than actually having the cells die and be born. It allows a much faster progression of steps, and more control over the game as a whole. No need to deal with mutations as generations progress, etc.

There is another problem with neighbor signaling. Ideally, corners and edges should have the same effect. But corner cells are slightly further away from the central cell. As signal diffusion is a function of distance, this may cause a problem.

The final step in simulating the Game of Life is setting an initial configuration. Since “live” cells are dependant on AHL concentrations, adding AHL to the grid would effectively set cells “on.” One way to place the AHL in specific locations would be to put it in an inkjet cartridge and print the pattern onto the grid medium. Alternatively, the configuration could be pre-set on a transfer medium which is then placed on top of the grid. And the simplest method is just using a syringe to add drops of AHL where needed.

There are still some unsolved problems with all of the ideas outlined above. Very precise control over diffusion of the signaling mechanism is required. Controlling sensitivity of the signal sensing mechanisms must be precise as well. The game grid must be regularly placed identical cells, which is very hard to do with biological elements. Also, these solutions would all necessarily be implementations of an asynchronous game of life. "Clocking" the system would require yet another signaling mechanism, and probably outside control. Finally, the Game of Life itself is very sensitive to initial conditions. Small variations in initial configurations results in dramatic differences after a few generations.

The conclusions we have made are that it is not very difficult to create a game similar to Conway's, but implementing his exact rules requires a great deal of precision that may not be technically feasible. It is our opinion that interesting results, and possibly even universal computation, could be obtained from a biologically-based game of life. The elements of randomness that would be introduced to the game may actually allow more interesting games. With Conway's Game of Life, many configurations soon result in stasis or repeated patterns. An element of random diffusion, cell activity, etc would make stasis configurations and infinitely repeating patterns rarer.

Web sites consulted, and source of pictures:
http://www.wikipedia.com/wiki/Conway%2527s_Game_of_Life
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